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STREAM TRANSMISSION METHOD AND DEVICE

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FIELD OF THE INVENTION

In general, the present invention relates to the field of communication systems. More specifically, the present invention relates to the transmission of data streams by a transmitter of communication system.

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BACKGROUND OF THE INVENTION

Bell Labs Layered Space-Time ("BLAST") is a prior art technique for sending multiple data streams from a single transmitting device and may use successive cancellation to recover the transmitted symbols. Each data

20 stream is transmitted with the same average power, and in order to perform successive cancellation, the optimal cancellation order of the data streams at the receiver needs to be determined. The prior art determination of the optimal ordering requires either channel knowledge at the transmitter to solve the ordering problem or a computationally complex algorithm in the receiver to

25 determine the optimal ordering. Having channel knowledge at the transmitter requires a large amount of feedback in mobile channels, and transmitting each data stream with the same power requires a successive cancellation algorithm at the receiver to determine the ordering of the data streams. The consequence of both solutions is a burdensome, complex computation being

30 performed by the transmitter or receiver, respectively.

Thus, there is a need for a new and unique data stream transmission method.

SUMMARY OF THE INVENTION

One form of the present invention is a method of operating a
transmitter comprising a determination of an unequal weighting of a plurality
of stream weights. In one aspect, the unequal weighting is accomplished by a
determination of a mean square error for each stream weight of a plurality of
stream weights, a determination of a first stream weight of the plurality of
stream weights having the largest mean square error, an increase in a power
of the first stream weight, and a decrease in a power of each stream weight of
the plurality of stream weights excluding the first stream weight. In a second
aspect, the unequal weighting is accomplished by an initialization of a first
stream weight, an increase in the first stream weight by a product of a power
variable and an increment, and a determination of a plurality of stream
weights excluding the first stream weight as a function of a corresponding
mean square error.

The foregoing form as well as other forms, features and advantages of
the invention will become further apparent from the following detailed
description of the presently preferred embodiment, read in conjunction with
the accompanying drawings. The detailed description and drawings are
merely illustrative of the invention rather than limiting, the scope of the
invention being defined by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates one embodiment of a transmitter in accordance with
the present invention;

FIG. 2 illustrates a flowchart representative of a stream weighting
determination method in accordance with the present invention;

FIG. 3 illustrates a flowchart representative of a first embodiment of the
stream weighting method of **FIG. 2** in accordance with the present invention;
and

FIG. 4 illustrates a flowchart representative of a second embodiment of the stream weighting method of FIG. 2 in accordance with the present invention.

5   DETAILED DESCRIPTION OF THE
     PRESENTLY PREFERRED EMBODIMENTS

FIG. 1 illustrates one embodiment of a transmitter in accordance with one embodiment of the present invention. In the illustrated embodiment, a
10   transmitter 10 comprises a new and unique stream weight module 11, a plurality of conventional mixers 12_1-12_n, a plurality of conventional transmitting units 13_1-13_n, and a plurality of conventional antennas 14_1-14_n. The stream weight module 11 provides a plurality of stream weights α_1-α_n to the mixers 12_1-12_n, respectively. The mixers 12_1-12_n conventionally mix the stream
15   weights α_1-α_n with a plurality of data streams$_{1-n}$, respectively, whereby the transmitting units 13_1-13_n and the antennas 14_1-14_n conventionally provide a plurality of transmission signals (not shown).

The stream weight module 11 can be implemented in hardware (analog and/or digital), software, or a combination of hardware and software. A
20   functional description of the stream weight module 11 will now be provided herein in the context of an execution of a flowchart 20, a flowchart 30, and a flowchart 50 by the stream weight module 11. The stream weight module 11, as will be appreciated by those having ordinary skill in the art from the subsequent description herein, can be employed within various
25   communications systems, such as, for example, a orthogonal frequency division multiplexing ("OFDM") system, a spread OFDM system, a single carrier system, a code division multiple access ("CDMA") system, and an interleaved frequency division multiple access ("IFDMA") system. Those having ordinary skill in the art will further appreciate a sequential operation of
30   various stages of the stream weight module 11 (e.g., in a software implementation) and a concurrent operation of various stages of the stream weight module 11 (e.g., in a hardware implementation).

Because the determination of the unequal weightings for the stream weight module **11** requires some assumptions about the type of receiver that receives the signal transmitted from the transmitter **10**, the received signal is now described. The signal from the transmitter **10** received at a receiving unit

5   may be expressed in the frequency domain according to the following equation [1]:

$$\mathbf{Y}(k) = \sum_{\ell=1}^{n} \alpha_\ell \mathbf{H}_\ell(k) x_\ell(k) + \mathbf{N}(k)$$

[1]

10   where k is an integer that may indicate the subcarrier number (or frequency bin), $\mathbf{Y}(k)$ is an $M_R \times 1$ vector where M_R is the number of receive antennas, $\mathbf{H}_\ell(k)$ is the $M_R \times 1$ channel vector for stream ℓ, $x_\ell(k)$ is the frequency-domain data symbol for stream ℓ on subcarrier k (for single-carrier, $x_\ell(k)$ is the Fast Fourier Transform ("FFT") of N time-domain symbols), and $\mathbf{N}(k)$ is

15   additive noise that may have covariance matrix $\sigma^2 \mathbf{I}$ where σ^2 is the noise power. The noise power is important in determining the best unequal stream weights as described below.

The determination of an unequal weighting of stream weights by the stream weight module **11** requires the transmitter to assume a type of

20   demodulation used by the receiver. If the receiver performs successive cancellation (as is known in the art), the received symbols can be estimated according to the following equation [2]:

$$r_\ell(k) = \mathbf{w}_\ell^H(k)\{\mathbf{Y}(k) - \sum_{p=1}^{\ell-1} \mathbf{H}_\ell(k)\hat{x}_\ell(k)\}$$

25   [2]

where $\mathbf{w}_\ell(k)$ is given by the following equation [3]:

$$\mathbf{w}_\ell(k) = \alpha_\ell \left(\sigma^2 \mathbf{I} + \sum_{p=\ell}^{n} \alpha_p^2 \mathbf{H}_p(k) \mathbf{H}_p^H(k) \right)^{-1} \mathbf{H}_\ell(k)$$

[3]

and for single carrier, $\hat{x}_\ell(k)$ is given by the following equation [4]:

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$$\hat{x}_\ell(k) = \mathrm{FFT}(\mathrm{slice}\{\mathrm{IFFT}[r_\ell(k)]\})$$

[4]

where IFFT denotes an inverse FFT, and the slice operation refers to a

10   symbol decision operation.

The idea of one embodiment of the present invention is to find the unequal stream weights that improve the mean square error performance of the successive cancellation receiver and allow the receiver to demodulate the data streams in an order known by the receiver to thereby thus avoid a need

15   by the receiver to determine an optimal stream demodulating order. The stream demodulation order is set in equation [2]. In one embodiment, the stream demodulation ordering is from data $stream_1$ to data $stream_n$. Other predetermined orderings can also be used in alternative embodiments, such as, for example, the stream demodulation ordering can be from data $stream_n$

20   to data $stream_1$.

Each mean square error equation subsequently described herein assumes the successive cancellation operations described above.

FIG. 2 illustrates the flowchart **20** as a representation of a stream weighting method in accordance with the present invention. The stream

25   weight module **11** initiates a stage **S22** of the flowchart **20** upon an operational activation of the transmitter **10**. During the stage **S22**, the stream weight module **11** determines an equal weighting for the stream weights α_1-α_n. In one embodiment, the equal weighting is dynamically determined, such as, for example, by an execution of one or more equations in real time by the

30   stream weight module **11**. In another embodiment, the equal weighting is

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pre-determined and stored whereby the stream weight module **11** retrieves the appropriate weight value for the stream weights α_1-α_n in real time.

Upon completion of the stage **S22**, the stream weight module **11** proceeds to a stage **S24** of the flowchart **20**. In one embodiment, the stage

5   **S22** is completed by the stream weight module **11** within a prescribed time period as determined by the operational specification of a communication system employing the stream weight module **11**. During the stage **S24**, the stream weight module **11** determines an unequal weighting of the stream weights α_1-α_n whereby at least two or more of the stream weights α_1-α_n have

10   unequal weight values. In one embodiment, the unequal weighting is dynamically determined, such as, for example, by an execution of one or more equations in real time by the stream weight module **11**. In another embodiment, the unequal weighting is pre-determined and stored whereby the stream weight module **11** retrieves the appropriate weight values for the

15   stream weights α_1-α_n in real time.

During a stage **S26** of the flowchart **20**, the stream weight module **11** ascertains a need for reiterating a determination of the unequal weighting of the stream weights α_1-α_n. In one embodiment, the stream weight module **11** proceeds to stage **S24** to perform an additional determination of the unequal

20   weighting when the current unequal weighting determination fails to achieve an optimal power allocation of the transmitted signals as determined by the operational specification of a communication system employing the stream weight module **11**. Conversely, the stream weight module **11** proceeds to terminate the flowchart **20** when the current unequal weighting determination

25   achieves an optimal power allocation of the transmitted signals.

In the embodiments where the unequal weighting of stream weights α_1-α_n is pre-determined and stored, stage **S22** may be omitted and stage **S24** can determine the unequal weighting of stream weights α_1-α_n from a lookup table operation. Additionally, a receiver may determine the unequal weighting

30   of stream weights α_1-α_n and provide such to stream weight module **11**.

Those having ordinary skill in the art will appreciate various benefits of flowchart **20**, such as, for example, improved receiver performance as

measured by a bit error rate and simplified successive cancellation demodulation because the data streams will be decoded in order (i.e., the demodulation ordering of the streams does not need to be determined by the receiver).

5   **FIG. 3** illustrates a flowchart **30** as a representation of one embodiment of flowchart **20**. During a stage **S32**, the stream weight module **11** determines an equal weighting of the stream weights α_1-α_n. In one embodiment of the stage **S32**, the equal weighting of the stream weights α_1-α_n are determined in accordance with the following equation [5]:

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$$\alpha_i = \frac{1}{\sqrt{n}}$$

[5]

where i = 1 to n, and n is the number of data $stream_1$-data $stream_n$.

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Upon completion of the stage **S32**, the stream weight module **11** proceeds to a stage **S34** of the flowchart **30** to establish an initial value for an increment s, and a statistical nature of channel vector $H_\ell(k)$ (for ℓ=1,...n). The statistical nature of $H_\ell(k)$ is used because the true channel in equation [1] may

20   not be known by the transmitter **10** and thus when the unequal power weights are determined, a model for channel vector $H_\ell(k)$ may be employed. In one embodiment of the stage **S34**, the initial value of the increment s is an arbitrarily small number (e.g., 0.001). In another embodiment of the stage **S34**, the initial value of the increment s is determined in accordance with the

25   following equation [6]:

$$s = \frac{1}{4\sqrt{n}}$$

[6]

In one embodiment of the stage **S34**, the statistical nature of channel vector $\mathbf{H}_\ell(k)$ (for $\ell=1,...n$) is determined whereby the stream weights α_1-α_n can be averaged over at least one realization of channel vector $\mathbf{H}_\ell(k)$. Specifically, the elements of channel vector $\mathbf{H}_\ell(k)$ can be formed at each k by generating

5   independent unit variance complex Gaussian random variables to approximate independent fading as is known in the art. In another embodiment of stage **S34**, channel vector $\mathbf{H}_\ell(k)$ is generated as a FFT of some number (e.g., a L number) of time taps where the time taps span the expected delay spread of the channel and are generated as independent

10   complex Gaussian random variables having some variance (e.g., 1/L).

Upon completion of the stage **S34**, the stream weight module **11** proceeds to a stage **S36** of the flowchart **30** to determine a mean square error ("MSE") for each stream$_1$-stream$_n$ in accordance with the following equation [7]:

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$$\mathrm{MSE}_\ell = \sum_{k=0}^{N-1} \frac{1}{1 + \alpha_\ell^2 \mathbf{H}_\ell^H(k)\mathbf{Q}_\ell^{-1}(k)\mathbf{H}_\ell(k)}$$

[7]

where $\mathbf{Q}_\ell(k)$ is determined in accordance with the following equation

20   [8]:

$$\mathbf{Q}_\ell(k) = \sigma^2 \mathbf{I} + \sum_{p=\ell+1}^{n} \alpha_p^2 \mathbf{H}_p(k)\mathbf{H}_p^H(k)$$

[8]

25   From equation [8], the noise power σ^2 of the receiver is needed to determine $\mathbf{Q}_\ell(k)$. Thus, the noise power σ^2 of the receiver is vital to a determination of the unequal weighting of stream weights α_1-α_n.

Upon completion of the stage **S36**, the stream weight module **11** proceeds to a stage **S38** of the flowchart **30** to determine the stream weight

from the stream weights α_1-α_n that has the largest MSE as determined during the stage **S36** in accordance with equations [7] and [8]. The stream weight having the highest MSE is referred to as stream weight α_{max}.

5 Upon completion of the stage **S38** of the flowchart **30**, a power of the stream weight α_{max} is increased by increment s during a stage **S40** of the flowchart **30** and the remaining stream weights are decreased in power during a stage **S42** of the flowchart **30** to realize the following equation [9]:

$$\sum_{\ell=1}^{n} \alpha_\ell^2 = 1$$

10   [9]

An unequal weighting of the stream weights α_1-α_n is achieved upon a completion of the stage **S42** of the flowchart **30**. The stream weight module **11** thereafter proceeds to a stage **S44** of the flowchart **30** to ascertain a need
15 for an additional iteration of the stages **S36-S42** by ascertaining whether the MSE of each stream weight α_1-α_n according to equations [7] and [8] are approximately equal, such as, for example, when the MSE of each stream weight α_1-α_n is within 0.001 of each other. If so, the stream weight module **11** terminates the flowchart **30**. Otherwise, the stream weight module **11**
20 proceeds to stages **S36-S42** for an additional determination of an unequal weighting of stream weight α_1-α_n.

In an alternative embodiment of the flowchart **30**, the stage **S32** may be omitted.

FIG. 4 illustrates a flowchart **50** as a representation of a second
25 embodiment of flowchart **20** (**FIG. 2**). During a stage **S52** of the flowchart **50**, the stream weight module **11** initializes stream weight α_n. In one embodiment of the stage **S52**, stream weight α_n is initialized in accordance with the following equation [10]:

$$\alpha_n = \frac{1}{2\sqrt{n}}$$

[10]

Upon completion of the stage **S52**, the stream weight module **11**

5   proceeds to a stage **S54** of the flowchart **50** to establish an initial value for an

increment s and a statistical nature of channel vector $\mathbf{H}_\ell(k)$ (for $\ell=0,\ldots n$) as

previously described herein in a connection with stage **S34** of flowchart **30**

(**FIG. 3**). Additionally, a resolution value E is established during stage **S54**. In

one embodiment, the resolution value E is 0.001.

10   Upon completion of the stage **S54**, the stream weight module **11**

proceeds to a stage **S56** of the flowchart **50** to determine a weighting of the

stream weights α_1-α_{n-1}. In one embodiment, the weighting of the stream

weights α_1-α_{n-1} are determined in accordance with the following equation [11]:

15   $$\alpha_\ell^2 = \frac{1}{\mathrm{MSE}_n} \sum_{k=0}^{N-1} \frac{1}{\mathbf{H}_\ell^H(k)\mathbf{Q}_\ell^{-1}(k)\mathbf{H}_\ell(k)}$$

[11]

where MSE_n and $\mathbf{Q}_\ell(k)$ are determined in accordance with equations [7]

and [8], respectively.

20   Upon completion of the stage **S56**, the stream weight module **11**

proceeds to a stage **S58** of the flowchart **50** to determine a power variable c.

In one embodiment, the power variable c is determined in accordance with the

following equation [12]:

25   $$c = sign(1 - \sum_{\ell=1}^{n} \alpha_\ell^2)$$

[12]

where $sign(x)=+1$ if $x>0$, $sign(x)=0$ if $x=0$, and $sign(x)=-1$ if $x<0$.

Upon completion of the stage **S58**, the stream weight module **11** sequentially proceeds to a stage.**S60** of the flowchart **50** to increase the weighting of stream weights α_n by a product of power variable c and increment s, a stage **S62** of the flowchart **50** to divide the increment s by a

5   factor of two, and a stage **S64** of the flowchart **50** to determine the weighting of the stream weights α_1-α_{n-1} as previously described in connection with stage **S56**.

An unequal weighting of the stream weights α_1-α_n is achieved upon a completion of the stage **S64** of the flowchart **50**. The stream weight module

10   **11** thereafter proceeds to a stage **S66** of the flowchart **50** to ascertain a need for an additional iteration of stages **S58-S64** by comparing increment s and resolution value E. Stream weight module **11** proceeds to stage **S58** when increment s is greater than resolution value E. Otherwise, the stream weight module **11** terminates the flowchart **50**.

15   The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that

20   come within the meaning and range of equivalency of the claims are to be embraced within their scope.